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P. Naitoh
T. L. Kelly
H. Babkoff

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NAVAL HEALTH RESEARCH CENTER
P.O. BOX 85122
SAN DIEGO, CALIFORNIA 92186-5122

NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
BETHESDA, MARYLAND



NAPPING, STIMULANT, AND FOUR CHOICE PERFORMANCE

Paul Naitoh
Tamsin L. Kelly
H. Babkoff*

Naval Health Research Center
P. O. Box 85122
San Diego, California 92166-5122

*Department of Psychology
Bar-Ilan University
Ramat-Gan, Israel

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SUMMARY

The effectiveness of naps in preventing performance degradation during a continuous work due to sleep loss was determined and compared with that of a stimulant, pemoline (Cylert). Three performance measures, i.e., the percent correct, reaction time, and the number of problems attempted, were obtained from the four choice serial reaction time task. These measures were used to evaluate the relative effectiveness of naps compared with pemoline.

The nap schedule examined in this study consisted of 20-min naps every 6 hours for 64 continuous hours. The pemoline dose of 37.5 mg was administered in a double blind manner every 12 hours. The timing of the nap was synchronized with the administrations of pemoline so that the first, third, fifth, and seventh naps were coincided with the administration of the drug.

In analysis of performance scores, the complex demodulation was used to examine a monotonic trend in the data, independent of circadian rhythm. The trend has been shown previously to sensitively reflect the effects of increased sleepiness and fatigue during a continuous work period.

The results showed that the 20-min naps, as well as 37.5 mg doses of pemoline taken prophylactically before the accumulation of sleep debt, were able to prevent cognitive decrements in response accuracy due to sleep loss. The 20-min naps were not as effective as pemoline in maintaining reaction time at the baseline level, but they helped to reduce a degree of behavioral slowing. Since the Four Choice task is self-paced and the number of responses is dependent on the subjects' willingness to keep responding, both pemoline and the 20-min naps did not prevent an overall decline in the number of problems attempted to be resolved.

The results suggested that the 20-min naps and pemoline are effective in maintaining cognitive and psychomotor functions which support performance accuracy and reaction time for a 64-hour continuous period. Previously published reports on the effects of pemoline and naps on a more extensive performance assessment battery indicates, however, that further studies are necessary before pemoline or naps are put into a practical use.



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INTRODUCTION

The primary purpose of this paper is to determine whether a short sleep (nap) can maintain human cognitive functions during a long continuous work period. In continuous work environments, the normal 7-8 hour period of nocturnal sleep is not allowed. Instead, work continues in time periods longer than 24 hours. A long work period causes cognitive decrements due to fatigue and sleepiness. Can naps prevent such decrements?

More specifically, can a sleep/wake schedule of a 20-min sleep every 6 hours prevent cognitive degradation during a continuous work period of 64 hours? The present chapter reports on the effects of the 20-min/340-min sleep/wake schedule on cognitive functions during a 64-hr work period.

The 20/340 sleep/wake schedule was chosen for the study on the basis of previously published experimental studies. They suggest that short naps prevent cognitive decrements during a long continuous work period, (Lubin et al., 1976; Mullaney et al., 1983; Stampi, 1989). (15)

This chapter also compares the effectiveness of such naps in maintaining cognitive function with that of a stimulant. We have previously reported on the effectiveness of the stimulant, pemoline, in preventing performance degradation during a 64-hr continuous work period (Babkoff et al., 1990; Kelly et al., 1990; Matteson et al., 1990). Nevhouse et al. (1989) reported that a 20 mg dose of d-amphetamine successfully reduced the cognitive decrements due to 48 hours of total sleep deprivation. Rogers et al. (1989) observed that 300 mg of caffeine administered at 2315 prevented cognitive and psychomotor decrements during an overnight continuous work period (from 1700 to 0845 the following morning). Decrement were expected in overnight work due to the early morning circadian low.

Can naps of 20 minutes every 6 hours started before the accumulation of sleep debt, i.e., sleep taken prophylactically, be as effective as d-amphetamine, pemoline and caffeine in maintaining cognitive functions? A comparison of cognitive benefits gained by naps with those of taking a stimulant will provide critical information for managing sleep in continuous work environments. Sleep has an advantage over stimulants in maintaining performance because it is not addictive and can be used repeatedly, whereas frequent use of stimulants is not recommended. On the other hand, are the beneficial effects of napping strong and reliable enough? The comparisons between the effects of naps and those of stimulants provide an unique

approach in research efforts to find the methods to counteracting the effects of sleep loss.

Lastly, the present chapter shows the results of using complex demodulation (Granger and Hatanaka, 1964; Redmond et al., 1982; Sing et al., 1985) to evaluate performance changes in a continuous work environment. Previously published studies show that the recuperative power of naps in improving cognitive efficiency is generally small, especially with a continuous work duration of less than 72 hours, as in the present study (Naitoh et al., 1981, 1982, 1989a&b). Hence, it is difficult to detect these small improvements with classical statistics, such as analysis of variance (ANOVA). The presence of a strong circadian rhythm in task performance makes statistical evaluation even more difficult as it masks small changes in a trend.

This chapter uses a type of time-series analysis, complex demodulation, to tease out the monotonic sleep loss effects from the circadian rhythmic component in the task performance data. A number of researchers (Thorne et al., 1983; Sing et al., 1985; Babkoff et al., in press) have shown that partitioning a total variance into the monotonic and rhythmic components, as achieved by complex demodulation, will improve the clarity and power of data interpretation.

Our studies can be regarded as part of a growing research effort on polyphasic (more than one sleep episode per 24 hrs) sleep and its effects on cognition and psychomotor skills. The present chapter reports on polyphasic sleep, having four 20-min sleep periods per sidereal day. Some researchers describe this polyphasic sleep as a "short 6-hr day" schedule when "a day" is specified arbitrarily to consist of one sleep period (e.g., 20-min) and one wake period (e.g., 340-min). Stampi (1989) has cited several studies on a "short day," e.g., the 60/360 sleep/wake pattern of "7-hr day" (Mullaney et al., 1983) and the 60/160 sleep/wake pattern of "3.7-hr day" (Lubin et al., 1976).

Our studies can also be viewed as part of the research efforts to determine the effects of shortening hours of sleep on performance. However, almost all of the partial sleep deprivation studies conducted in the past are concerned with shortening one sleep period per 24-hr day. That monophasic sleep data may not be directly relevant to our 6-hr day study. Polyphasic sleep may or may not cause partial sleep deprivation. In our studies of the "6-hr day," subjects slept a total of 80 minutes per 24-hr

day, resulting in partial sleep deprivation, whereas in the 90-min day study of Carskadon et al. (1975, 1977), subjects slept 8 hours in a 24-hr day.

Characterization of our studies is offered here in terms of the concepts of polyphasic sleep, "short day" and "partial sleep deprivation," to avoid confusion.

EXPERIMENTAL PROCEDURES

SUBJECTS

The present chapter focuses on the data from two groups of young male naval volunteers in a short sleep study (Nap and No-Nap groups), and also from two additional groups taken from a large laboratory study involving the prophylactic use of stimulants (Pemoline and Placebo groups).

In these two protocols, up to four volunteer subjects were studied at once at the sleep laboratory located at the Naval Hospital, San Diego, starting on Monday. Subjects stayed at the laboratory for 5 days and 4 nights until the completion of experimental protocol and their release on Friday morning.

The subjects spent Monday being familiarized with the study protocol and also trained on the use of a psychological performance battery (PAB). All subjects slept for about 8 hours on Monday night. They were awakened at 0620 Tuesday and started a 64-hr continuous work period.

20-MIN NAP GROUP: Fifteen naval volunteers started this group nap study where they did not get a regular nocturnal sleep of 8 hours, but were allowed 20 minutes of rest every 6 hours for a total of 8 times during a 64-hr continuous work period. However, two volunteers dropped out of the study due to sickness, and four other volunteers opted to withdraw from the study. The remaining 9 subjects (average age = 20.0 ± 2.2) completed the experimental protocol and their data have been used in this chapter.

The first 20-min sleep was scheduled at 2150 on Tuesday. The second 20-min sleep was at 0350 on Wednesday, 6 hrs later. Other scheduled sleep periods were: 0950 (Wed), 1550 (Wed), 2150 (Wed), 0350 (Thur), 0950 (Thur), and 1550 (Thur).

A NO-NAP CONTROL GROUP: Ten naval volunteers (average age = 20.4 ± 1.9) started in this group, and all ten completed the protocol which required that they stay awake for a 64-hr period. The data from these totally sleep deprived volunteers were compared with those subjects who had naps.

A PEMOLINE GROUP: A group of 12 young, healthy, male naval volunteers (average age = 20.2 ± 1.5) participated in a double blind study for the prophylactic use of pemoline. Their experimental protocol was identical to that used for the nap study. This group received the first medication of 37.5 mg of pemoline (Cylert) at 2200 Tuesday evening. The medication was repeated every 12 hours during the 64-hr, continuous work period (a total of four doses). The time of the additional medication was at 1000 (Wed), 2200 (Wed), and 1000 (Thur). Six hours after each pemoline administration, a placebo capsule was given to the subjects. These placebos were added to protect the double-blind nature of the study, because the other drug evaluated in this study (but not discussed in this chapter), methylphenidate, required dosing every 6 hours.

Pemoline is an oxizolidine compound. It has less sympathomimetic cardiovascular effects than methylphenidate (Abbott, 1975) and acts primarily through the dopaminergic system (Molina and Orsinger, 1981). It has a long half-life (12 hours), reaching its peak serum level in 2-4 hours. Pemoline generally has to be given for a period of time before significant benefit is seen in minimal brain dysfunction. However, significant counteraction of fatigue has been reported with a single dose (Orzack et al., 1968; Havard, 1970).

A PLACEBO GROUP: Twelve volunteers served as a placebo group (age = 22.1 ± 3.1). The placebo group is identical to the no-nap group in that both experienced a total sleep deprivation of 64 hours. However, placebo subjects received a placebo capsule every 6 hours starting at 2200 Tuesday.

MEASUREMENTS OF CHANGES IN PERFORMANCE

The changes in cognitive and psychomotor functions were measured by a computerized (Apple II based) Performance Assessment Battery (PAB). In this chapter, the changes in the four-choice serial reaction time task (Wilkinson, 1969; Wilkinson and Houghton, 1975) will be described.

The "four-choice" task was administered as part of test sessions given every three hours, and it lasted for 11 minutes (actual duration was a little longer than 11 minutes because the computer was waiting for a response when the 11 minutes was completed. The task did not end until the response was entered). The first four-choice administration was at 0845 (Tuesday), about two hours after awakening from the baseline sleep. In this self-paced test, a "star" appears in one of the four positions, forming a

square, and it continues to be displayed until the subject presses the response key. The response keys are arranged in a square, similar to the stimuli, and the subject responds by pressing the key whose location corresponds to that of the stimulus.

Three scores were extracted from the four-choice task. They are (1) percent correct in each session, a measure of performance accuracy, (2) total number of responses in each session, a measure of psychomotor productivity, and (3) average reaction time in each session to indicate speed in responding.

MEASUREMENT OF CHANGES IN SLEEP

During the short sleeps in the nap group, the central C3 electroencephalogram (EEG), left and right electrooculograms (EOGs), and submental electromyogram (EMG) were recorded on cassette tapes with portable sleep recording systems. To complete sleep staging, these cassette tapes were played back to produce paper recordings of sleep. The manual by Rechtschaffen-Kales (1968) was used to score sleep stages.

Four sleep quantitative measures were calculated to determine how much the subjects had slept during each sleep epoch. These measures were (1) sleep latency, (2) total sleep time (a sum of stages 2, 3, 4 and REM), (3) minutes of slow wave (a sum of stages 3 and 4) sleep, and (4) sleep efficiency. Sleep efficiency is a percentage of total sleep time (the sum of stages 2, 3, 4 and REM) over the total bedtime of 20 minutes.

APPLICATIONS OF COMPLEX DEMODULATION

Complex Demodulation analysis (CD) were performed on an IBM compatible Personal Computer for analysis with a Complex Demodulation (CD) program (Sing et al., 1985). Sing et al. hypothesizes that a time series $X(t)$ consists of the trend component $c(t)$, the set of rhythmic components $d(t)$, and random component $e(t)$.

$$X(t) = c(t) + d(t) + e(t)$$

A set of many performance scores obtained from a subject who was regularly tested for the four-choice task is amenable to analysis by complex demodulation. Previous applications of CD to performance data of sleep deprived subjects have demonstrated the appropriateness of the model (e.g., Babkoff et al., 1985; Thorne et al., 1983).

The CD separates the trend and rhythmic components by means of multiplying original time series data, e.g., performance scores, by sinusoidal waves

with experimenter-chosen frequencies, e.g., 1 cycle per day, and then, filtering out the products. The CD can be regarded as an application of a radio-engineering "heterodyne" technique, modified to operate within a biopsychological spectrum range (see Granger and Hatanaka, 1964; Sing et al., 1985).

The first pass of the CD over the original data sets isolates the trend from the rhythmic components in the data. The trend is a time series newly created by the CD program, and it can be plotted against the original data to show how closely and smoothly it follows the data.

Then, the trend is subtracted from the data to obtain the residual (another time series) which will reflect $d(t)$ and $e(t)$:

$$\text{Residual } X(t) = d(t) + e(t)$$

The second CD pass decomposes the residual into the constituent rhythmic components. In the present study, only a 1 cycle per day rhythmic component was extracted.

The interpretation of the magnitude of the circadian component detected in the data by the CD is straightforward. Some experimental treatments are known to change amplitude and/or phase of the circadian rhythm. However, critical review of experimental conditions is required before interpretation of the trend in the data can be made. A trend of declining four-choice task scores over a 64-hr work period may represent decreasing willingness to work, increasing sleepiness, or increasing boredom. In the present study, the performance trend of the experimental groups (i.e., 20-min sleep group and Pemoline group) were compared with that of their control groups (i.e., No-Nap group and Placebo group). The slope differences were interpreted to show how powerful 20-minute naps or pemoline were in counteracting the performance degrading effects of sleep loss.

RESULTS

NAP EFFICIENCY

Table 1 shows some of the selected sleep measures for each of the eight 20-min epochs.

The ANOVA was calculated for each sleep measure, using an analysis design: Subjects \times Day \times Sleep Time, where the last two factors were repeatedly measured. "Day 1" represented the first four sleep periods, and "Day 2," the last four sleep periods (see Table 1). "Sleep Time" represented four time periods, 0345, 0945, 1545, and 2145.

TABLE 1

20-min Ultrashort Sleep

| Sleep ID# | Time | Hr- of Prior Wakefulness | Average (in minutes) | | (in %) | | |
|--------------|-------------|-----------------------------|----------------------|------------------|--------|-----|---------------------|
| | | | TBT | Sleep Latency | TST | SWS | Sleep Efficiency |
| 01 | 2145 (Tue) | 15 | 19.4 | 10.0 | 8.0 | 3.8 | 38.2 |
| 02 | 0345 (Wed) | 21 | 20.4 | 5.3 | 15.4 | 7.1 | 67.3 |
| 03 | 0945 (Wed) | 27 | 21.6 | 6.8 | 15.6 | 9.5 | 65.5 |
| 04 | 1545 (Wed) | 33 | 21.0 | 4.8 | 16.6 | 9.6 | 71.4 |
| 05 | 2145 (Wed) | 39 | 19.1 | 5.7 | 14.1 | 8.5 | 66.6 |
| 06 | 0345 (Thur) | 45 | 21.1 | 4.7 | 17.3 | 7.5 | 73.5 |
| 07 | 0945 (Thur) | 51 | 19.8 | 6.4 | 14.6 | 6.2 | 66.1 |
| 08 | 1545 (Thur) | 57 | 21.0 | 4.8 | 16.6 | 9.6 | 71.4 |

TBT = Total Bed Time; Limited to 20-min, TST = Total Sleep Time = Sleep stages 2, 3, 4 and REM combined. SWS = Slow Wave Sleep = Sleep stages 3 and 4 combined.

None of the sleep measures showed overall significant differences by the ANOVA's. Post-hoc analysis using the Duncan procedure showed that the sleep measures from the first 20-min sleep were significantly different from the others at 5% or better.

The average total bed time (TBT) was found to range from 19-21 minutes which was close to the planned 20-min duration. After excluding the first 20-min sleep data, the average sleep efficiency was found to be 68%, i.e., the subjects slept 68% (13.6-min) of a 20-min sleep epoch.

PICTORIAL DESCRIPTIONS OF DATA

Although this chapter reports primarily on four groups (20-min Nap, No-Nap, Pemoline and Placebo), Figure 1 includes an additional group which was given methylphenidate. This figure shows percent correct on the Four-Choice task. The eight arrows show when the 20-minute naps were taken. Pemoline was given at the local time indicated by the first, third, sixth, and seventh arrows.

ANALYSIS OF FOUR CHOICE DATA WITH CD

Figure 2 illustrates how the CD detects monotonic trend (the inverted triangles) and 1 cycle per day component (1 CPD; filled inverted triangles) in a data set (filled circles). The sum of the monotonic trend, 1 CPD rhythmic components, and the remainder will regenerate the data. In this chapter, the slope of the CD-detected trend is discussed, but no further reference will be made to the strong circadian rhythm in the data.

ANALYSIS OF FOUR CHOICE DATA WITH CLASSICAL STATISTICS

Figure 3 shows the average percent correct response with ± 1 standard error bars on the Four-Choice task for the No-Nap (N=10) and 20-min Nap (N=9) groups. Figure 4 shows a similar plot for the Placebo and Pemoline groups.

Analysis of variance was performed using the data from all of the subjects in the No-Nap group and the 20-min Nap group. The ANOVA was run with the analysis design of Sleep x Day x Task Session (where Sleep indicated group, No-Nap or Nap). Table 2 shows the definition of these factors, Day and Task Sessions.

In terms of the percent correct measure, ANOVA showed no significant main effect for the Sleep factor ($F(1,17)=1.67$, $p<.217$), and significant main effects for the Day ($F(1,17)=10.03$, $p<.006$), and for Task Sessions

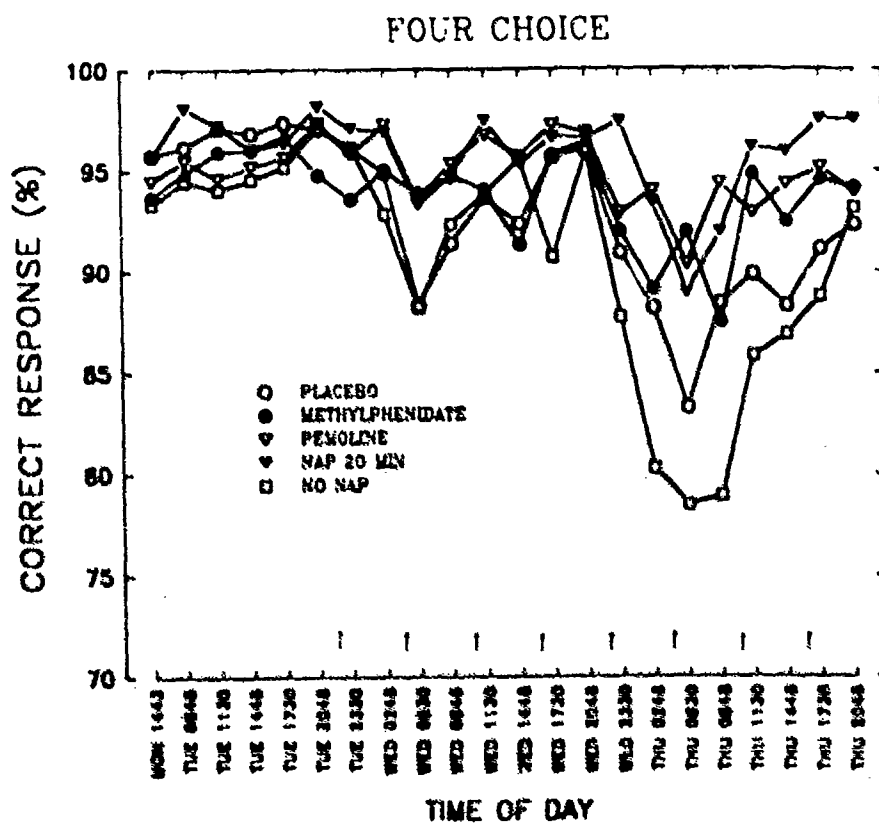


Figure 1 The percent correct response in performing the Four Choice task by subjects in five groups. The X axis shows the local time when the test sessions were held. The first data point obtained at 1443 on Monday is not a part of the regular test sessions. This paper does not indicate time when 20-min naps are taken.

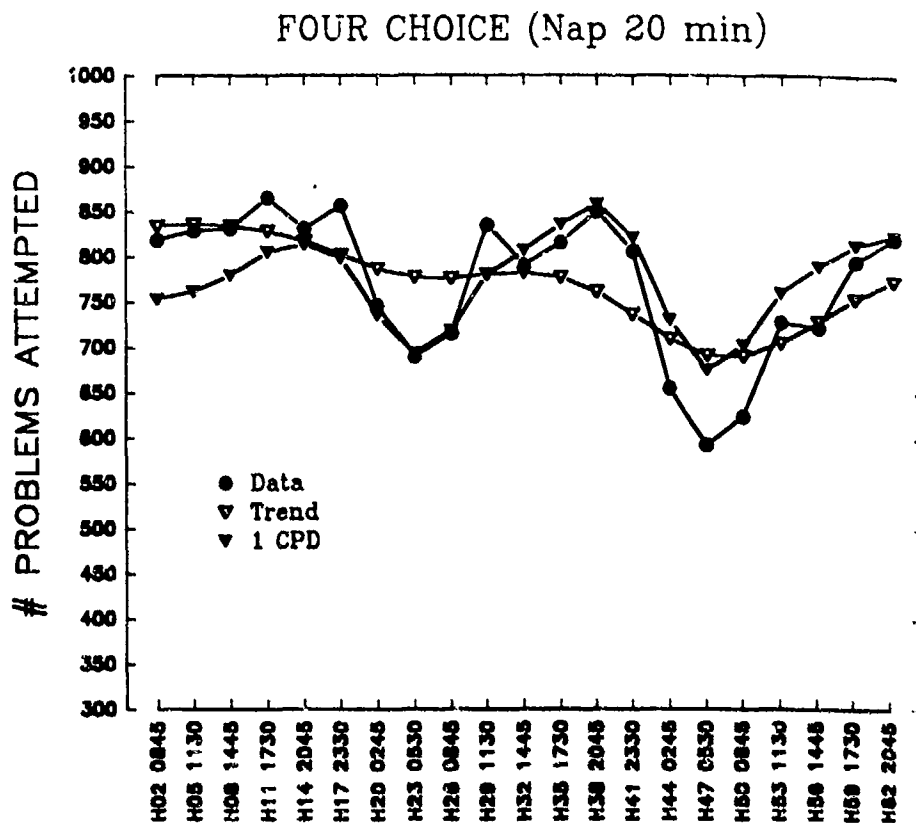


Figure 2 Demonstration of modeling performance scores (number of problems attempted) with Complex Demodulation. CD fits a trend and 1 cycle per day rhythmic activity to represent the data. In this example, average scores obtained from 9 subjects are used in CD analysis. The X axis is labelled in two ways, in Local Time and the H(ours) since the start of the 64-hour continuous work period.

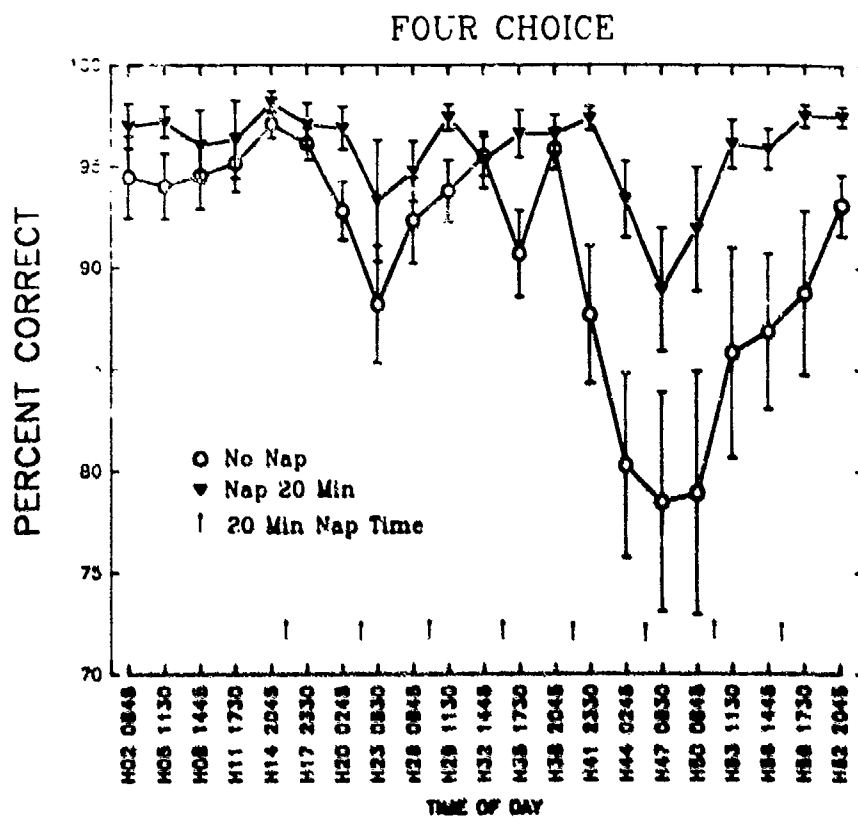


Figure 3 The percent correct response in performing Four Choice task by subjects in the No-Nap (N=9) and 20-min Nap (N=10) groups. The plot shows the means of performance scores ± 1 standard error bars.

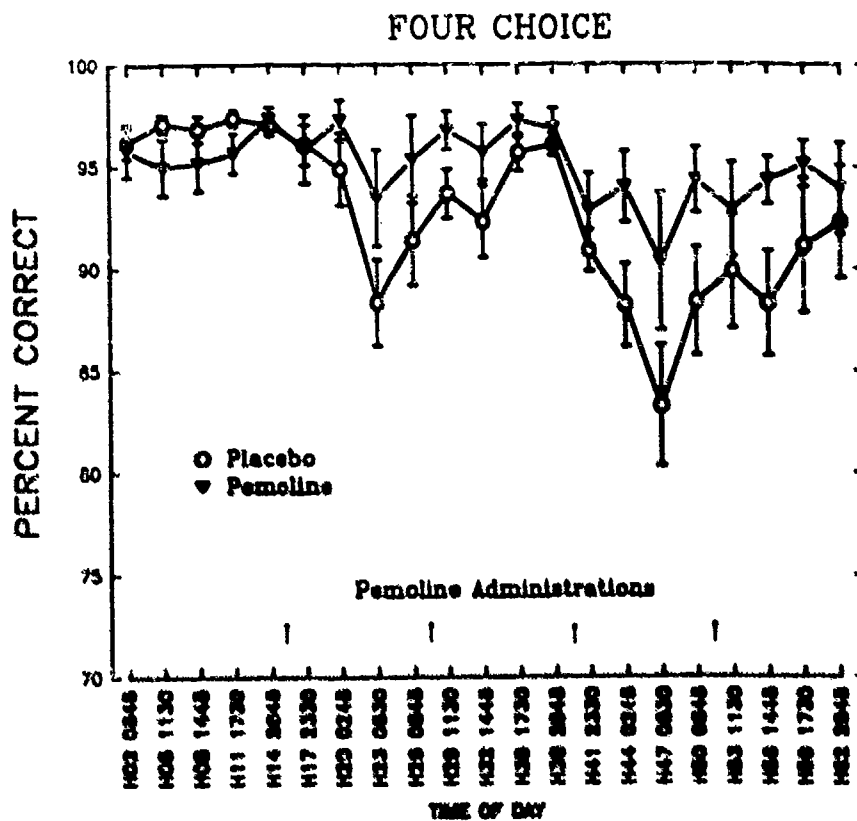


Figure 4 The percent correct response in performing Four Choice task by subjects in the Pemoline (N=12) and Placebo (N=12) groups.

TABLE 2
Analysis of Four Choice Data

| DAY 1 | | | DAY 2 | | |
|------------------------|------------|---|------------------------|-------------|---|
| TASK SESSION #ID | TIME | HRS OF PRIOR AWAKE DURATION (HRS) | TASK SESSION ID# | TIME | HRS OF PRIOR AWAKE DURATION (HRS) |
| 07 | 2330 (Tue) | 17 | 15 | 2330 (Wed) | 41 |
| 08 | 0245 (Wed) | 20 | 16 | 0245 (Thur) | 44 |
| 09 | 0530 (Wed) | 23 | 17 | 0530 (Thur) | 47 |
| 10 | 0845 (Wed) | 26 | 18 | 0845 (Thur) | 50 |
| 11 | 1130 (Wed) | 29 | 19 | 1130 (Thur) | 53 |
| 12 | 1445 (Wed) | 32 | 20 | 1445 (Thur) | 56 |
| 13 | 1730 (Wed) | 35 | 21 | 1730 (Thur) | 59 |
| 14 | 2045 (Wed) | 38 | 22 | 2045 (Thur) | 62 |

See Figure 1

($F(1,17)=5.71$, $p<.000$). However, Day interacted significantly with the Task Session (Day x Task Session: $F(1,17)=3.34$, $p<.003$).

Instead of exploring a complex pattern resulting from the interactions, the t tests were repeatedly applied to evaluate the differences between the 20 min Nap and No-Nap groups, and between the Pemoline and Placebo groups. The statistical evaluation has been conducted in terms of three performance measures. The t tests results are listed in Table 3. The pattern of significance shown in Table 3 shows only sporadic non-systematic beneficial effects with naps and pemoline. Table 3 shows, however, that performance deterioration occurred at 0245, corresponding to the circadian trough. It

Table 3
Statistical Differences in Four-Choice Performance (Raw Data)

| TIME | Prior Awake (Hrs) | Percent Correct | | | Reaction Time | | | Problems Attempted | | |
|-------|-------------------------|-------------------|----------------------------|------|-------------------|----------------------------|------|--------------------|----------------------------|------|
| | | 20min | | | 20min | | | 20min | | |
| | | Nap vs. No-Nap | Pemoline vs. Placebo | t | Nap vs. No-Nap | Pemoline vs. Placebo | t | Nap vs. No-Nap | Pemoline vs. Placebo | t |
| 0845 | 02 | - | - | - | - | - | - | - | - | - |
| 1130 | 05 | - | - | - | - | - | - | - | - | - |
| 1445 | 08 | - | - | - | - | - | - | - | - | - |
| 1730 | 11 | - | - | - | - | - | - | - | - | - |
| 2045 | 14 | - | - | - | - | - | - | - | - | - |
| 2330 | 17 | - | - | - | - | - | - | - | - | - |
| <hr/> | | | | | | | | | | |
| 0245 | 20 | 2.23 | .039 | - | - | -2.64 | .015 | - | 2.23 | .037 |
| 0530 | 23 | - | - | - | - | -2.94 | .008 | - | 2.82 | .010 |
| 0845 | 26 | - | - | - | - | - | - | - | - | - |
| 1130 | 29 | 2.12 | .049 | - | - | - | - | - | - | - |
| 1445 | 32 | - | - | - | - | - | - | - | - | - |
| 1730 | 35 | 2.35 | .031 | - | - | - | - | - | - | - |
| 2045 | 38 | - | - | - | - | - | - | - | - | - |
| 2330 | 41 | 2.67 | .016 | - | - | - | - | - | - | - |
| <hr/> | | | | | | | | | | |
| 0245 | 44 | 2.56 | .020 | 2.17 | .042 | - | - | - | - | - |
| 0530 | 47 | - | - | - | - | -3.01 | .006 | - | 2.47 | .022 |
| 0845 | 50 | - | - | - | - | - | - | - | - | - |
| 1130 | 53 | - | - | - | - | - | - | - | - | - |
| 1445 | 56 | 2.17 | .045 | 2.13 | .044 | -2.26 | .034 | - | - | - |
| 1730 | 59 | - | - | - | - | - | - | - | - | - |
| 2045 | 62 | 2.64 | .017 | - | - | - | - | - | - | - |

- = Not significant at 5% or better

showed further that two performance measures, reaction time and number of problems attempted, of those subjects in the 20-min Nap group did not differ significantly from those who remained awake.

ANALYSES OF FOUR CHOICE DATA WITH COMPLEX DEMODULATION

Figures 3 and 4 show that percent correct on Four-Choice had a prominent circadian component which could have masked a gradual performance decline. CD was applied to the data of all three performance measures of the Four-Choice task to detect the trend (the residual after removing the circadian component). The results of two trend analysis on the percent correct measure for the No-Nap and 20-min Nap groups are shown in Figure 5, and the Placebo and Pemoline groups in Figure 6.

The results of t tests on the trend data are listed in Table 4. The beneficial effect of the 20-min naps and 37.5 mg pemoline doses in preventing performance decrements are clear after 35 hours of continuous work. The local time corresponding to this 35-hour continuous work was 1730 local time, 6-7 hours before the start of the second circadian trough.

The beneficial effects of pemoline on accuracy disappeared near the end of the 64-hour work period, not because of deterioration of the Pemoline group, but because of improved accuracy in the Placebo group (see Figure 6). Comparing the Placebo group in Figure 6 with the No-Nap group in Figure 5, there appears to be a fairly strong "placebo effect."

The results of the CD-trend analysis on reaction time for the 20-min Nap and No-Nap groups are shown in Figure 7. Table 4 shows no significant differences in reaction time between the Nap and No-Nap groups. However, Figure 7 gives a different impression. Figure 7 shows the reaction times of the nap group were consistently, but not significantly, faster than the No-Nap group. The lack of significant differences appears to be due to the small number of subjects and large individual differences in reaction time scores.

Similar findings were made in the measure of Problems Attempted. The Nap and Pemoline groups were not statistically significant (Table 4) but they responded more often than their respective control groups.

COMPARISONS OF TRENDS AMONG NAP, PEMOLINE AND CONTROLS

As discussed previously in the statistical introduction of this chapter, the slopes of the trend lines (e.g., Figures 5, 6, and 7) show sleep loss effects on performance of the Placebo and No-Nap groups, with significant

Table 4
Statistical Differences in Four-Choice Performance (Trend)

| TIME | Prior Awake (Hrs) | Percent Correct | | | Reaction Time | | | Problems Attempted | | |
|-------|-------------------------|-------------------|----------------------------|------|-------------------|----------------------------|--------|--------------------|----------------------------|---|
| | | 20min | | | 20min | | | 20min | | |
| | | Nap vs. No-Nap | Pemoline vs. Placebo | t | Nap vs. No-Nap | Pemoline vs. Placebo | t | Nap vs. No-Nap | Pemoline vs. Placebo | t |
| 0845 | 02 | - | - | - | - | - | - | - | - | - |
| 1130 | 05 | - | - | - | - | - | - | - | - | - |
| 1445 | 08 | - | - | - | - | - | - | - | - | - |
| 1730 | 11 | - | - | - | - | - | - | - | - | - |
| 2045 | 14 | - | - | - | - | - | - | - | - | - |
| 2330 | 17 | - | - | - | - | - | - | - | - | - |
| <hr/> | | | | | | | | | | |
| 0245 | 20 | - | - | - | - | - | - | - | - | - |
| 0530 | 23 | - | - | - | - | - | - | - | - | - |
| 0845 | 26 | - | - | - | - | - | - | - | - | - |
| 1130 | 29 | - | - | - | - | - | - | - | - | - |
| 1445 | 32 | - | - | - | - | - | - | - | - | - |
| 1730 | 35 | 2.33 | .003 | 2.08 | .049 | - | -2.17 | .041 | - | - |
| 2045 | 38 | 2.78 | .015 | 2.17 | .041 | - | (-2.02 | .056) | - | - |
| 2330 | 41 | 2.86 | .001 | 2.61 | .016 | - | -2.17 | .041 | - | - |
| <hr/> | | | | | | | | | | |
| 0245 | 44 | 2.85 | .011 | 2.22 | .037 | - | -2.40 | .025 | - | - |
| 0530 | 47 | 2.80 | .012 | 2.14 | .043 | - | -2.61 | .016 | - | - |
| 0845 | 50 | 2.81 | .012 | - | - | - | -2.76 | .011 | - | - |
| 1130 | 53 | 2.68 | .016 | - | - | - | -2.70 | .013 | - | - |
| 1445 | 56 | 2.61 | .018 | - | - | - | -2.27 | .033 | - | - |
| 1730 | 59 | 2.52 | .022 | - | - | - | - | - | - | - |
| 2045 | 62 | 2.45 | .025 | - | - | - | - | - | - | - |

- = Not significant at 5% or better

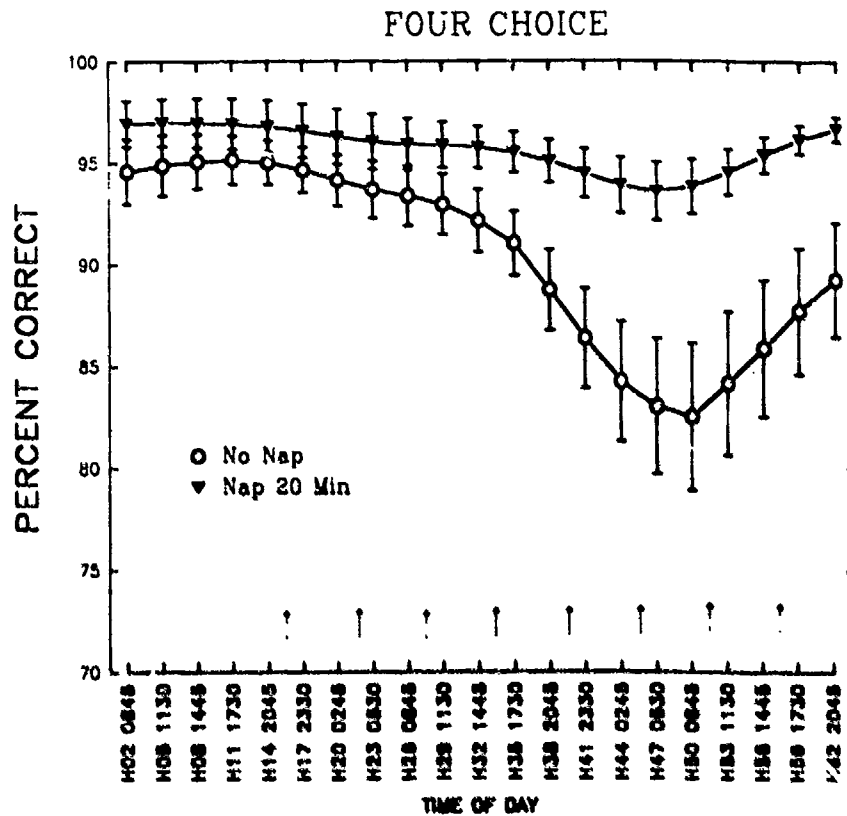


Figure 5 Trends extracted by the complex demodulation. The CD was applied to the percent correct scores of each subject individually to extract a trend in the data. Nine trends were averaged to create an average trend with ± 1 standard error bars for the No-Nap group. Similarly, 10 trends were averaged to create an average trend with ± 1 standard error bars for the 20-min Nap group.

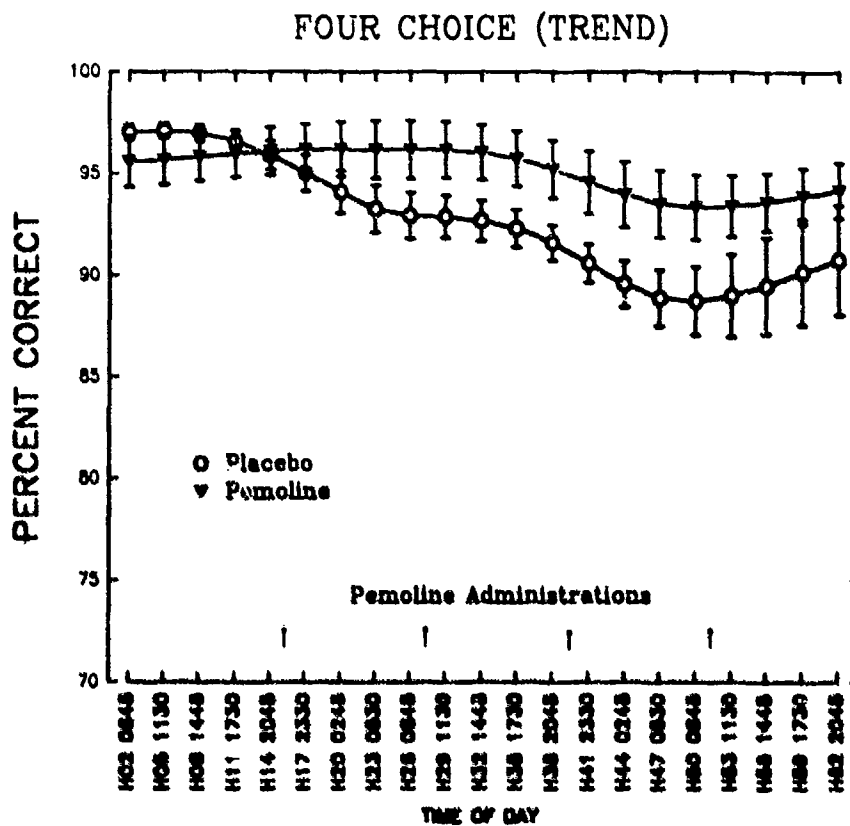


Figure 6 Average trends for the Placebo and Pemoline groups.

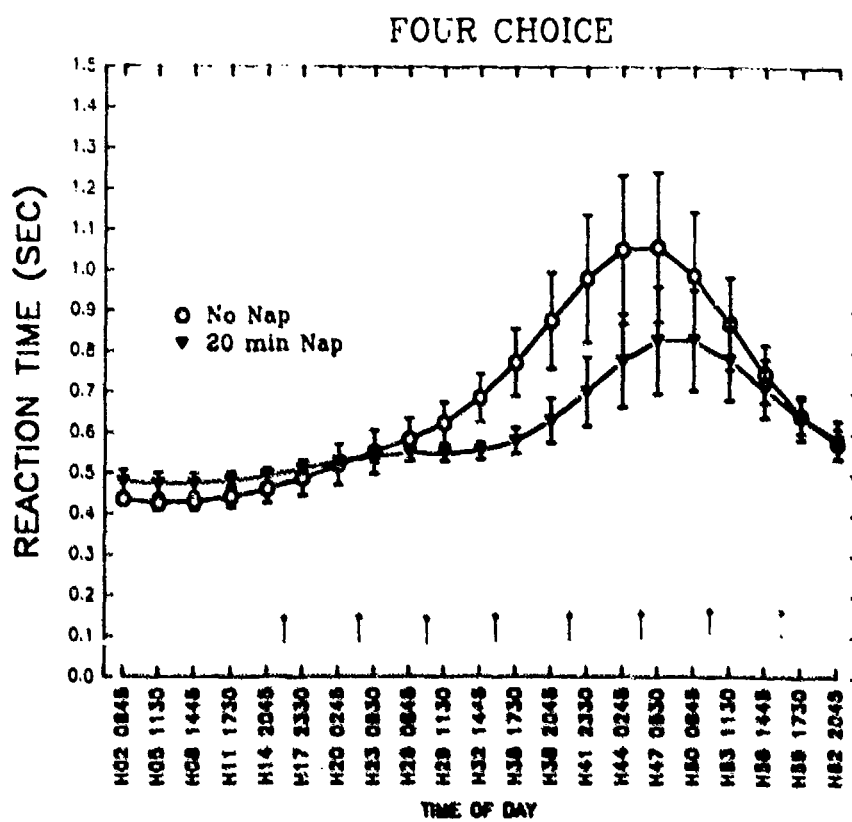


Figure 7 Average trends in the reaction time measure for the No-Nap and 20-min Nap groups.

benefits from naps or pemoline in counteracting the effects of sleep loss. In cases where the performance scores remained at the baseline level throughout the 64-hour work period, the trend slope will be small and appear as a flat horizontal line. The steeper the slope, the greater the changes in the performance scores. The simultaneous comparisons of the trends of the four groups, Nap, No-Nap, Pemoline, and Placebo, were made to determine a relative recuperative power from fatigue and sleep loss.

PERCENT CORRECT

The Nap and Pemoline groups (Figures 5 and 6) showed an almost flat horizontal trend, indicating that these two groups are almost identical and the subjects kept the baseline level of accuracy in performance. The slope of the Placebo group was a very small downward trend. The No-Nap group (Figure 5) showed a small downward slope, i.e., keeping the baseline reaction time up until 32 hours into the continuous work (1445 Wednesday). The small downward slope was, then, replaced by a very sharp downward slope lasting until 50 hours into the continuous work. A curious trend of improved performance, perhaps due to the end of study surge effect, started at 53 hours (1130 Thursday) and continued to the end of the study.

REACTION TIME

The Pemoline group had a trend with an almost zero slope, meaning that it kept the baseline level of performance throughout the study. Similarly, the performance trend of the Nap group had a near zero slope for the first 35 hours (until 1730 Wednesday) of the continuous work period. However, after 35 hours, the Nap group, as well as the two control groups, began to show a varying degree of slowing in reaction times. The reaction time of the Placebo group started a slowing trend at the session 17 hours into the continuous work. This slowing trend continued to 47 hours (0530 Thursday), after which the reaction time trend showed faster speed until the end of the study. Group differences in the trend were most prominent during the 35-53 hours of wakefulness. The No-Nap group had the largest slowing in reaction time, followed by the Placebo group, then the Nap group. The subjects in the Pemoline group slowed minimally.

NUMBER OF PROBLEMS ATTEMPTED

All four groups showed a trend where subjects did fewer problems beyond 47 hours (0530) of the 64-hour continuous work period. Then, they began to show a recovery which continued to the end of the study. The Pemoline group

attempted the largest number of problems. The No-Nap and Placebo (control) groups had similar downward trends, solving the fewest number of problems. The trend of the Nap group fell between the Pemoline group and the two control groups.

DISCUSSION AND CONCLUSIONS

Can a sleep/wake schedule of a 20-min sleep every 6 hours prevent the cognitive degradation expected during a 64-hour continuous work period? In other words, can a "short 6-hour day" maintain the baseline cognitive functions for almost 11 of the short days ($10 \text{ days} \times 6 \text{ hours} + 4 = 64 \text{ hours}$)?

The results of this study suggest that a 20-min nap taken every 6 hours will maintain the baseline level of cognitive functions necessary for maintaining accuracy of performance on the Four-Choice task. The naps also helped to reduce, but did not fully prevent, slowing in response speed, and failed to maintain the number of responses at a high baseline level. Under a "6 hour day" where total sleep is limited to 80 minutes per 24 hours, subjects slow their work pace slightly, but their responses remain accurate.

Stampi (1989) has written a literature review on naps and performance. The earliest "napping" and performance study was conducted by May Smith on herself (1916). She reduced her sleep from 8 hours a night to 5.5, 3.5, and 1.5 hours over three consecutive nights. The immediate effect was improvement in task performance. A decreased task performance occurred only during the day following a recovery sleep. To explain unaltered performance despite shortened sleep, she suggested that usually untapped reserves were being employed to compensate for undesirable effects of short sleep but they were eventually exhausted, resulting in poor performance during the days after recovery sleep. Other studies also showed little decrement in performance, i.e., small amounts of sleep seemed sufficient to prevent serious performance decrements (Friedmann et al., 1977; Rutenfranz et al., 1972; Webb and Agnev, 1965; Webb and Agnev, 1974).

However, Tilley and Wilkinson (1984) felt that the apparent power of a short nap to prevent performance decrements might be an artifact of the use of insensitive tests.

The effects of a short sleep over sleep architecture and moods, but not necessary over performance, has also been examined in laboratory experiments on "short day" and disrupted sleep (Bonnet, 1986; Carskadon and Dement,

1975, 1977; Lavie and Scherason, 1981; Lubin et al., 1976; MaGee et al., 1987; Moses et al., 1975; Weitzman et al., 1974).

An early "short day" study was conducted by Weitzman et al. (1974). Subjects were given a sleep/wake schedule of 1 hour sleep and 2 hours awake (i.e., a 3-hour day) for 10 calendar days. Under this sleep/wake schedule, total sleep was reduced from 7 hours per 24 hours during the baseline to about 4.5 hours (sleep efficiency of 56%), even though the subjects were given opportunity to sleep for 8 hours every 24 hours. REM sleep was reduced the most, while the least change was observed in Slow Wave Sleep. No performance and mood data were available in this report.

Carskadon and Dement (1975) examined a sleep/wake schedule of 30 minutes sleep and 60 minutes awake (90-minute day) for 5.3 calendar days. The total sleep time was reduced from about 8 hours to 5 hours per day (sleep efficiency of 63%). Sleepiness, as measured by the Stanford Sleepiness Scale, increased significantly during the first day of the study but decreased almost to the baseline over the next four days.

Lubin et al. (1976) reported on the effects of a sleep/wake schedule of a 60-min sleep and 160-min awake (a 220 min day) for 40 hours. They found that actual total sleep time averaged 6.1 hours/24 hours, subjects utilizing only 61% of bedtime for sleep. The prophylactic 1-hour naps every 220 minutes were observed to neutralize the loss of normal nocturnal sleep on the Wilkinson Auditory Vigilance and the Wilkinson Addition tasks. There was impairment in short-term memory involved in immediate recall of a list of words and increased sleepiness near the end of the 40 hour period.

Moses et al. (1975) summarized sleep efficiency and percent sleep stages of the subjects in the Lubin et al. study (1976), as well as those subjects in the study of Weitzman et al. (1974), and in Carskadon and Dement's study (1975). The ultrashort sleep pattern decreased sleep efficiency in all three studies, and the sleep efficiency fell from greater than 90% at baseline to 50%. Percentages of stage 1 and SWS increased, and percentages of stage 2 and REM decreased. The low sleep efficiency they have observed would suggest that ultrashort sleep schedules had resulted in much wasted time as subjects were unable to sleep.

Bonnet (1983) reported on a nocturnal experiment lasting two consecutive nights in which three groups of subjects were awakened repeatedly after each onset of stage 2 or REM sleep. One group was awakened after 1 minute, the

second group after 10 minutes, and the third group after 2.5 hours. Another group remained awake for the full 64-hour study as a totally sleep-deprived comparison group. Polygraphic sleep recordings were obtained and, each morning, subjects completed a 30 minute Wilkinson Addition test, a 30 minute Wilkinson Vigilance test, and a 10 minute simple reactions time test.

As expected, total sleep loss condition produced the greatest performance decrements. The performance of the subjects in the 1-minute sleep group the morning after the second sleep-fragmenting night were similar to those of the totally sleep-deprived. The group in the 10-min sleep condition did somewhat better than those in the 1-min state, and the 2.5-hour sleep condition produced the least decrement.

Polysomnographic analysis showed that subjects whose sleep was interrupted after the 1-min condition for two consecutive nights were able to sleep for 4-4.5 hours out of a total bedtime of 7 hours, with sleep efficiency of 67% and 62% for the first and second nights, respectively. SWS and REM sleep were essentially eliminated. The subjects in the 10-min condition were able to sleep for 6 hours, while those under the 2.5 hour condition slept 5-5.5 hours. The subjects in these groups experienced small reductions in stages REM and SWS. All three groups showed a significant rebound in SWS during the first recovery night and a significant rebound in REM sleep during the second recovery night.

MaGee et al. (1987) also showed a reduction in total sleep time from a 429-min to a 373-min control value, virtual elimination of SWS, and reduced REM in subjects whose sleep was interrupted every minute for one night by a beeping tone. The intensity of the tones was increased to 95 dB in the absence of the subject's response. Subjects were required to take a deep breath to indicate they were awake. Sleep efficiency was 79.1 as compared to 94.1% for the control group. The subjects experienced an increased daytime sleepiness as measured by the multiple sleep latency test (MSLT). Another group of subjects in this study, had their sleep interrupted every four minutes. The 4-minute sleep condition showed only a small reduction in SWS and sleep efficiency, no change in REM, and no increase in daytime sleepiness. Despite differences in the severity of awakening imposed on the subjects (problem solving in the Bonnet study vs. deep breathing in the MaGee et al.'s), the effects of the 1-min sleep on sleep architecture were comparable between these two studies, however, an exception was detrimental

effects on sleep showing after two consecutive nights in Bonnet's study. It might also be noted that the 4-min sleep in MaGee et al.'s study showed less of an effect on sleep than the 10-min sleep in the Bonnet study.

The present study also observed relatively poor use of a 20-min nap period. The sleep efficiency ranged between 65.5%-73.5% (except the first nap with very poor sleep efficiency of 38.2%).

Most importantly, Bonnet observed that "periodic sleep fragmentation at a rate of once per minute for 2 nights" (page 9 of Bonnet (1985)), or putting it differently, the 1-min sleep caused a level of behavior decline similar to that observed after 40-60 hours of total sleep loss.

Short sleep/wake patterns were actually used among yachtsmen on solo yacht races (Stampi, 1985a, 1985b, 1988, 1989). The solo yachtsmen accumulated an average total sleep duration of 6.3 hours per 24 hours, but most (68%) of them took many short naps lasting 10-20 minutes, i.e., they have adopted a polyphasic sleep pattern. Stampi found a significant negative correlation between mean sleep length and performance: sailors with the shortest sleep episodes finished highest in the sailing standings.

Another way to reduce sleepiness and fatigue of prolonged work would be to use stimulants. Newhouse et al. (1989) administered d-amphetamine to recover performance after 48 hours accumulated sleep loss during a continuous work period.

Pemoline was reported to be an effective drug in preventing attention deficit while performing a vigilance task (Orzack et al., 1968). Pemoline, at a dose level used in the present study, was effective in maintaining accuracy, response speed, and the number of problems attempted in each session. Pemoline has been reported to improve performance on the Wilkinson Addition test and the Digit Symbol Substitution test in the narcoleptics (Mitler et al., 1986). Pemoline is not addictive, and there is slight risk, if any, of recreational use. Our data indicates that pemoline is a promising stimulant for maintaining performance on tasks like the Four-Choice task. However, other data from the pemoline study report (Kelly et al., 1990), showed degradation in accuracy of Logical Reasoning toward the end of the sleep deprivation period. Hence, further study is required before pemoline can be recommended as an optimal stimulant to sustain cognitive functions during a continuous work period.

Analyses of performance scores with CD yielded a much clearer picture than standard statistical analyses. Instead of vaguely concluding that the beneficial effects of naps or pemoline were significant at various times of the day, the CD-derived trend analysis demonstrated that the benefit of a 20-min nap on performance accuracy began to show up 35 hours after the start of a continuous work period at 1730, local time, and continued to the end of the study, with a similar pattern for pemoline of shorter duration, perhaps due to a placebo effect in the control group. Similarly clear conclusions can be made in terms of Reaction Time.

Although a set of complex statistical calculations were made to model the performance scores to extract a trend from a time-series, very simple statistics were applied to characterize the trends, and differences in trends. Applications of more sophisticated multivariate statistics on the trends might demonstrate more details of the trends.

Two major issues remain unresolved in applications of naps to maintain performance. The results reported in this chapter show that the 20-min naps were helpful to maintain Four-Choice performance during a 64-hour continuous work period. This positive outlook on the naps' usefulness was realized, however, after a great deal of effort by the subjects to overcome "nap aversion." It is very difficult to wake-up from a short nap, particularly at certain times of the day, (actual local times vary from one individual to another) and, subjects had a sense of failure because they felt that their Four-Choice task performance shortly after a nap was poor, far below their standard. The negative affect, and the sense of performance failure (which was objectively not true), resulted in 4 out of 15 subjects quitting the study outright, and two more quitting because of illness. In contrast, 10 out of 10 subjects completed the 64-hr total sleep deprivation regimen, and we almost never had subjects drop out of other sleep deprivation studies of similar duration but not involving naps. Hence, there appears to be a need to reduce nap aversion, either by training to accept the process of struggling to wake up, or by a stimulant (e.g., caffeine), to help reduce the initial sleep inertia.

One possible countermeasure is raised by Spiegel's observation (1981) that the habitual nappers woke from a nap refreshed, whereas the non-habitual nappers did not. No survey was made with the subjects in the present study, but those subjects who quit the study could have been the

non-habitual nappers. It seems that a satisfying and refreshing nap is assured only with gaining experience of napping at any time of the day.

The purposes of examining the effects of short nap were (1) to determine whether these naps were effective in preventing deterioration of performance during sleep loss and (2) to compare this preventive (prophylactic) power of a nap to that of a moderate dose of a stimulant, pemoline (37.5 mg every 12 hours, a total of 4 doses in a 64-hour period of continuous work). The results of the present study appear to have strengthened the database of sleep management by showing that we can partially satisfy the sleep needs of workers who cannot sleep regularly for 7-8 hours every night with a 20 minute nap every 6 hours.

Sleep management concepts have been around for over 60 years since the publication of a book by Laird and Muller (1930). Sleep logistics (Naitoh and Angus, 1989) is a military application of sleep management, which stresses the importance of balancing the loss of manpower by permitting highly skilled and irreplaceable military personnel to sleep against gaining increased alertness and competence after sleep (Harris and O'Hanlon, 1972; Naitoh et al., 1986). This chapter is dedicated to Sleep Management and Sleep Logistics.

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